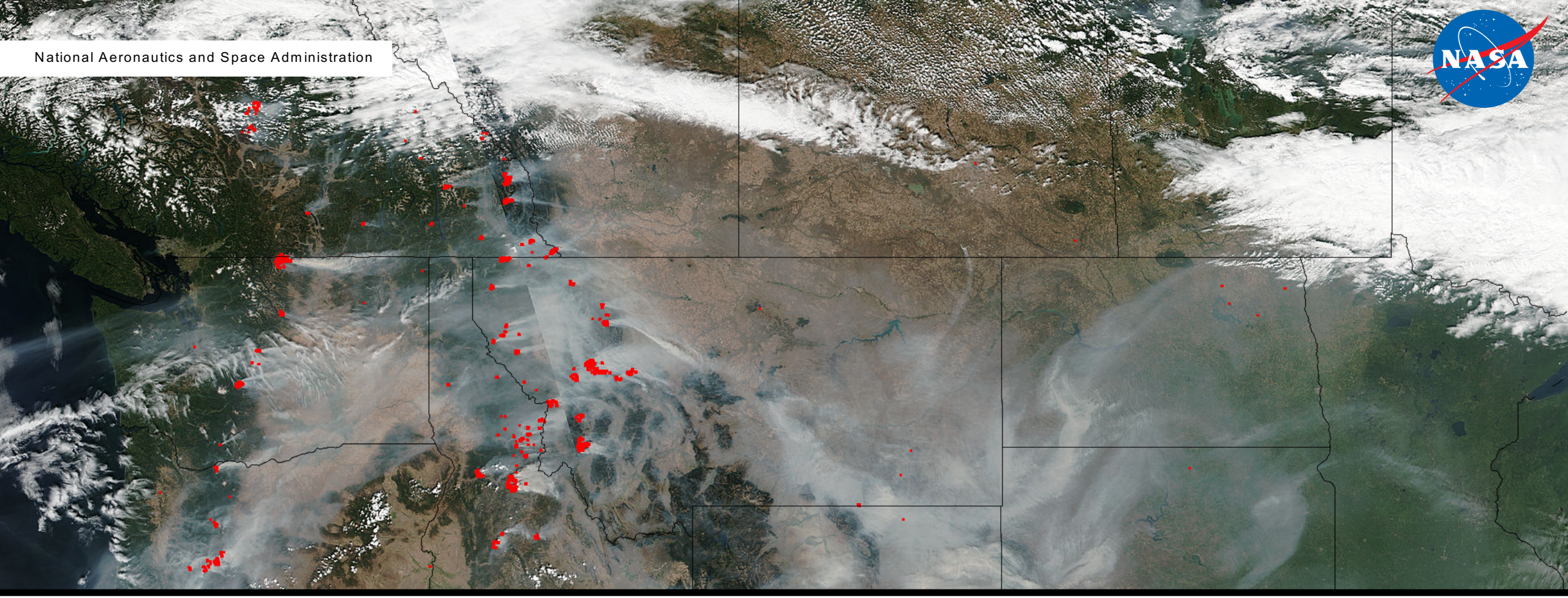
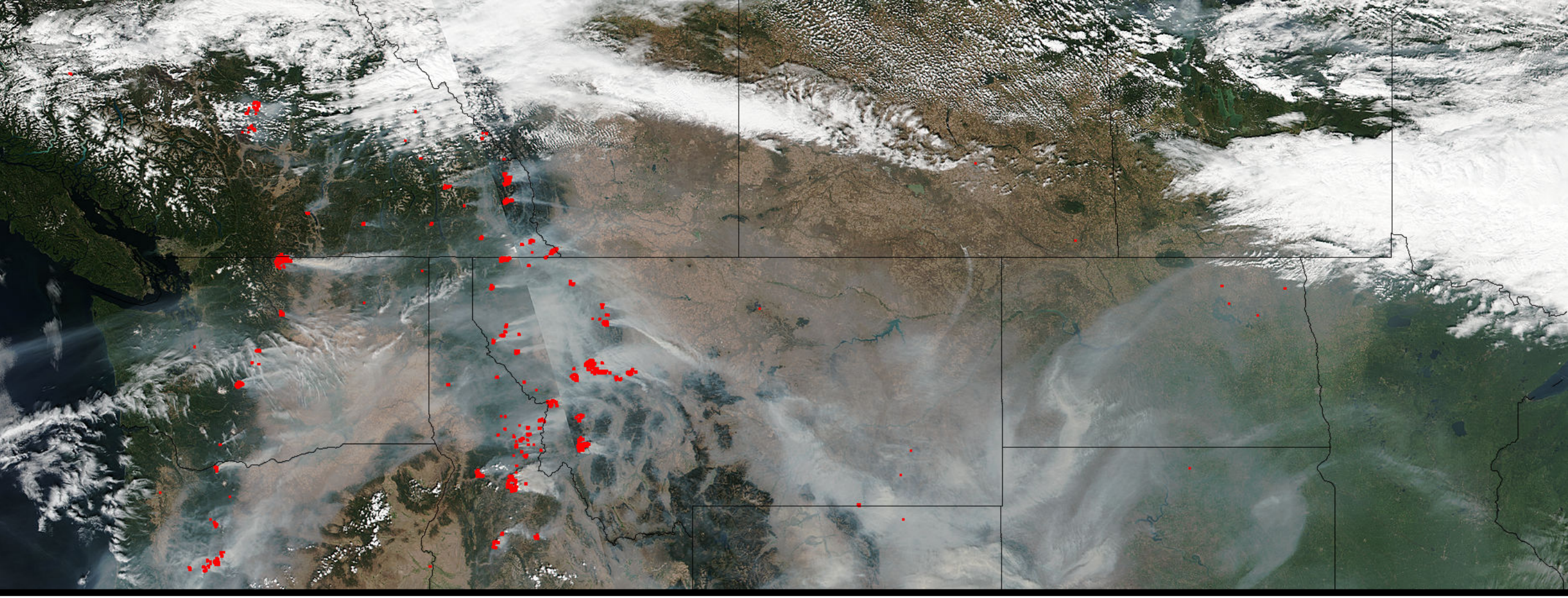


Air Quality Forecasting and the MERRA-2 Reanalysis

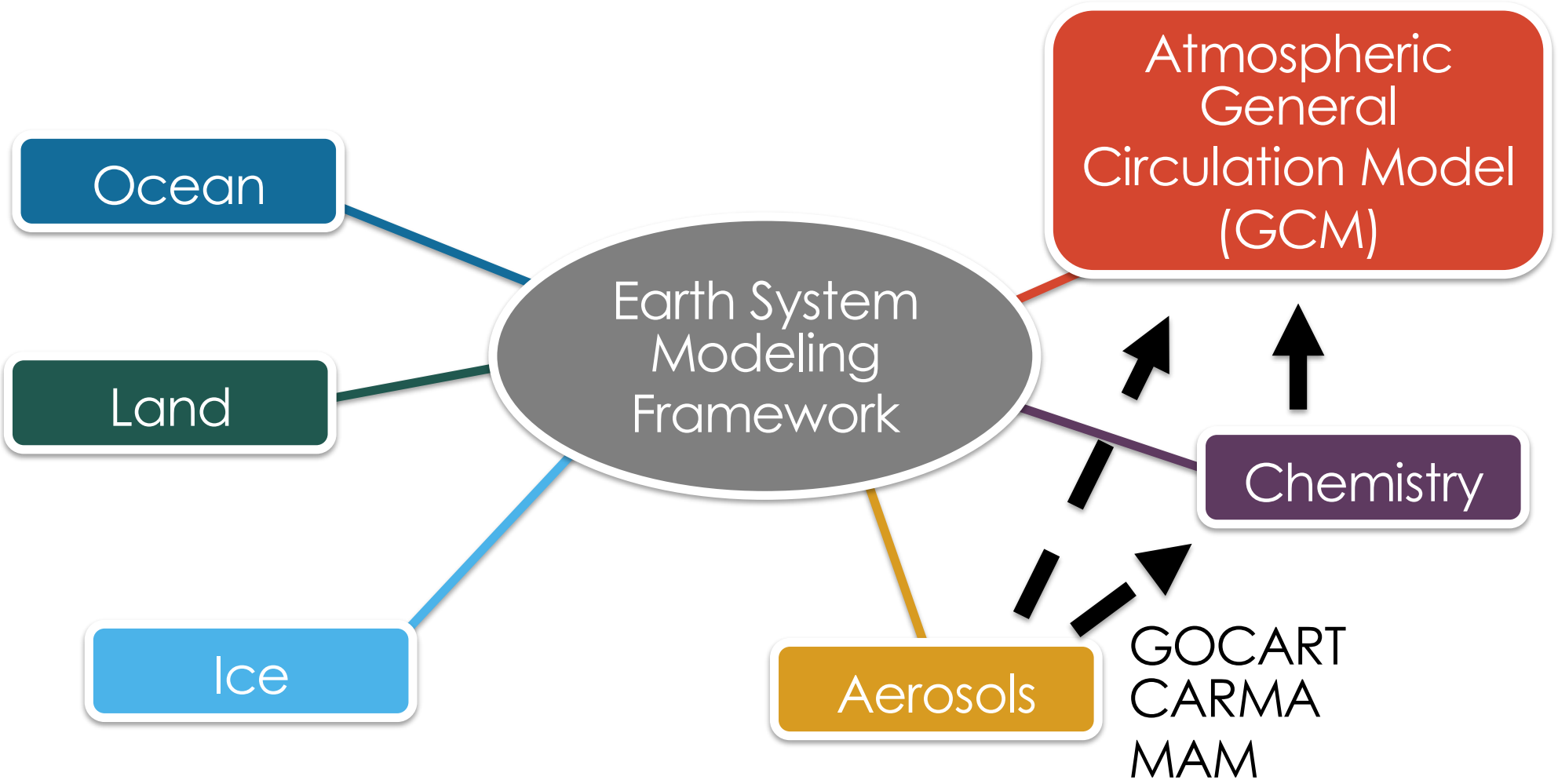
Melanie Follette-Cook and Pawan Gupta

Satellite Remote Sensing of Dust, Fires, Smoke, and Air Quality, July 10-12, 2018



MERRA-2 Reanalysis

NASA GEOS Earth System Model



Why data assimilation?

- Models are useful but have difficulty specifying emissions, resolving microphysical processes, and transport, leading to large uncertainties

- While there are a large number of aerosol sensors, there are still blind spots:
  - Measurements are usually vertically integrated
  - Diurnal cycle is not represented by polar orbiters

- Data assimilation can act as an integrator of model and observational information and a conveyor of past observations

What is reanalysis, and why do we do it?

What

- A consistent reprocessing of Earth system observations using a modern, unchanging data assimilation system
- Relies on models to interpret, relate, and combine different observations from multiple sources
- A successful reanalysis ***requires*** a good forecast model combined with bias-corrected and quality controlled observations

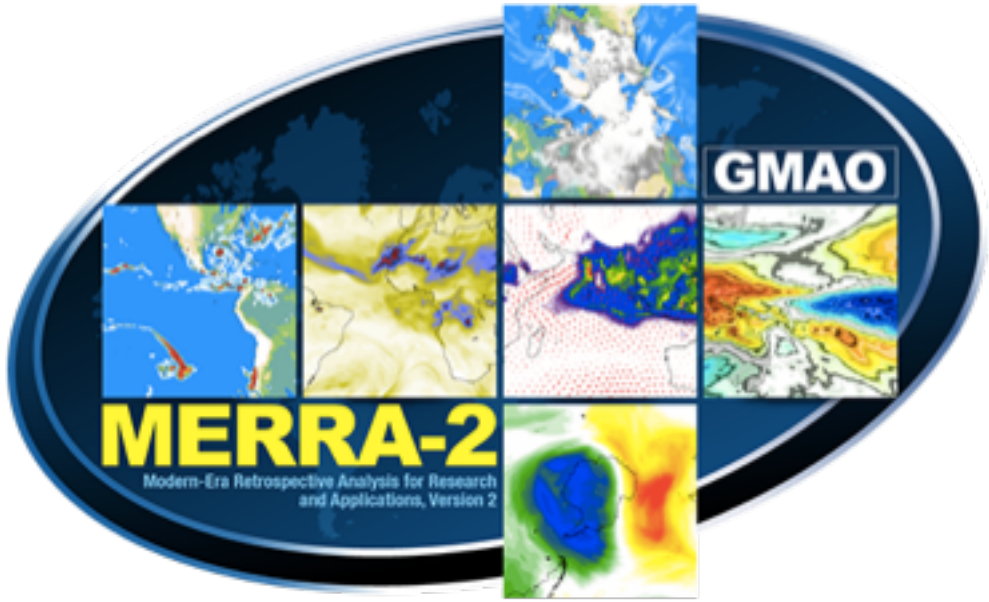
Why

- Produces multi-decadal, gridded datasets that estimate a large variety of Earth system variables, including ones that are not directly observed
- Has become fundamental to research and education in the Earth sciences

MERRA-2 Reanalysis

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

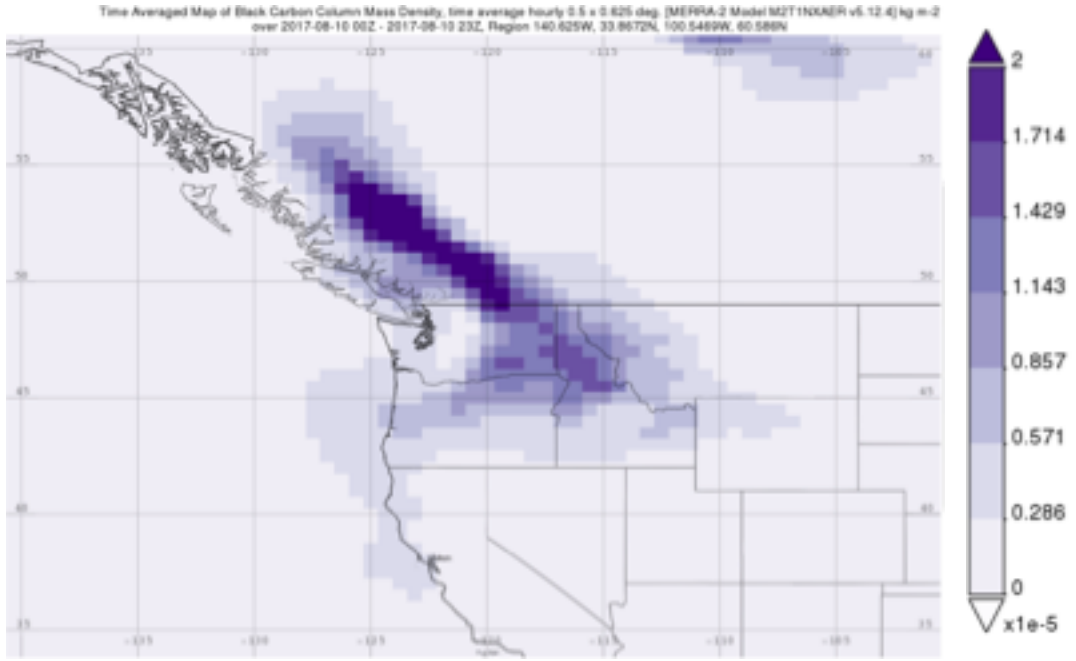
- Long-term, model-based analyses of multiple datasets using a fixed assimilation system
  - GEOS (Goddard Earth Observing System Model)
- The **M**odern-**E**ra **R**etrospective analysis for **R**esearch and **A**pplications version 2 (MERRA-2) provides data beginning in 1980 and runs a few weeks behind real-time
- MERRA-2 includes meteorology, stratospheric ozone, and aerosols at a spatial resolution of a 0.5° × 0.66° grid



Source: https://gmao.gsfc.nasa.gov/reanalysis/

MERRA-2 Reanalysis Example – August 10, 2017

MERRA-2 – Black Carbon



MODIS – Terra

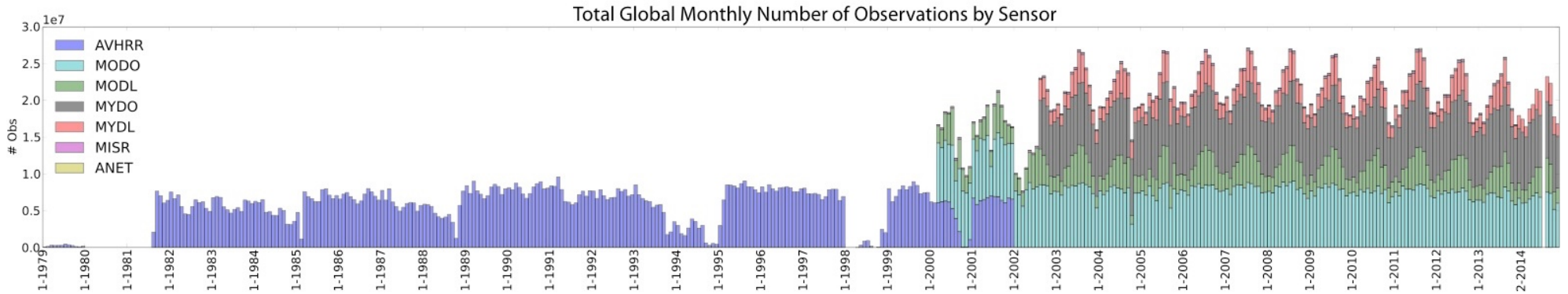
MERRA-2 Webpage Tour

https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/

Aerosol Observing System

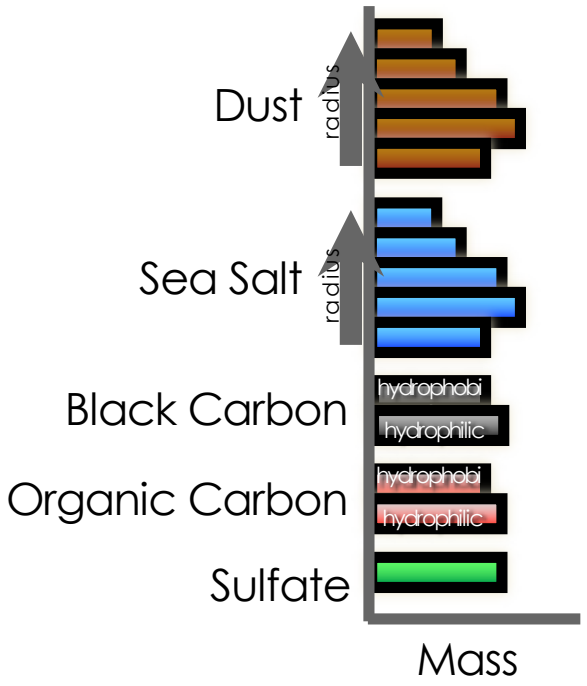
Sensor	Period	Remarks
AVHRR*	1979 – 2002	PATMOS-x; NNR; Ocean Only
AERONET	1999 – 2015	Ground-Based Stations
MODIS Terra*	2000 - present	C5; NNR; Separate Land and Ocean
MODIS Aqua*	2002 – present	C5; NNR; Separate Land and Ocean
MISR	2000 – 2014	Bright Surfaces (albedo > 0.15)

Total global monthly number of AOD observations, sensors marked with * multiplied by 10^7)



GOCART in GEOS-5

- Based on the Goddard Chemistry, Aerosol, Radiation and Transport Model (Chin et al. 2002)
- Sources and sinks for 5 non-interactive species



Dust: wind and topographic source, 5 mass bins

Sea Salt (SS): wind driven source, 5 mass bins

Black Carbon: anthropogenic & wildfire source, mass hydrophobic & hydrophilic

Organic Carbon: anthropogenic, biogenic, and wildfire source, mass hydrophobic and hydrophilic

Sulfate: anthropogenic and wildfire source of SO_2, oxidation to SO_4 mass

MERRA-2 Emissions

https://gmao.gsfc.nasa.gov/pubs/docs/Randles887.pdf

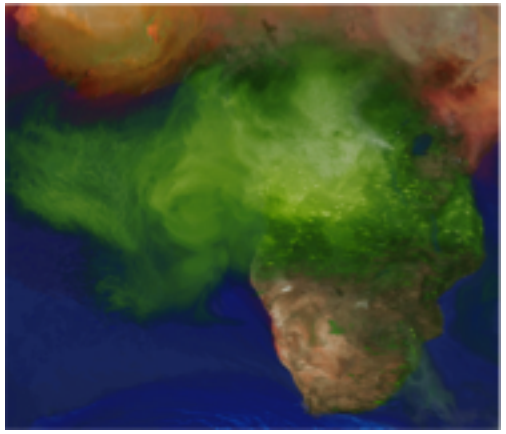
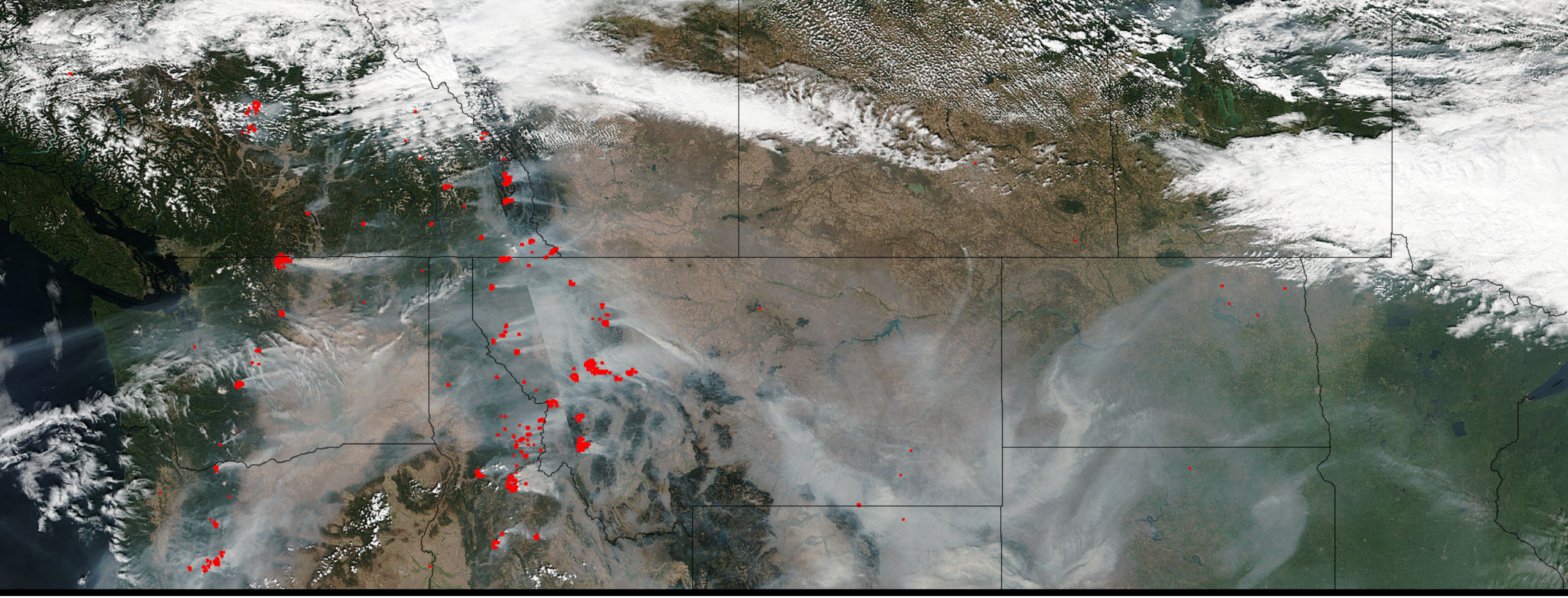


Table 2.1: Aerosol and precursor emissions in MERRA-2

Aerosol Type	Source	Temporal Resolution	Spatial Resolution[a,b]
Dust	Wind-driven emissions w/Ginoux et al. (2001) static topographic depression map	Model	0.3125°× 0.25°[c]
Sea Salt	Wind-driven emissions	Model	Model
Volcanic (SO_2)	AeroCom Phase II (HCA0 v2; Diehl et al., 2012)	Daily degassing (1980 – onwards) and daily eruptive (1980 – 2010)	Point-sources
Biogenic terpene	Guenther et al. (1995)	Monthly-mean climatology	2°× 2.5°
Di-Methyl Sulfide (DMS)	Lana et al. (2011)	Monthly-mean climatology	1°× 1°
Biomass Burning (SO_2, SO_4, POM, and BC)	scaled RETROv2 (Duncan et al., 2003)	Monthly-varying (1980 – 1996)	0.3125°× 0.25°
	scaled GFEDv3.1 (Randerson et al., 2006)	Monthly-varying (1997 – 2010)	0.3125°× 0.25°
	QFED 2.4-r6 (Darmenov and da Silva, 2015)	Daily-varying (2010 – onwards)	0.3125°× 0.25°
Anthropogenic SO_2	EDGARv4.2 (Energy + Non-Energy) (European Comission, 2011)	Annually-varying (1980 – 2008)	0.1°× 0.1°
Anthropogenic SO_4, POM, and BC	AeroCom Phase II (HCA0 v1; Diehl et al., 2012)	Annually-varying (1980 – 2006)	1°× 1°
International Ships SO_2	EDGARv4.1 (European Commission, 2010)	Annually-varying (1980 – 2005)	1°× 1°
International Ships SO_4, POM, and BC	AeroCom Phase II (HCA0 v1; Diehl et al., 2012)	Annually-varying (1980 – 2007)	1°× 1°
Aircraft SO_2	AeroCom Phase II (HCA0 v1; Diehl et al., 2012)	Monthly-varying (1980 – 2006)	1°× 1.25°× 72-levels

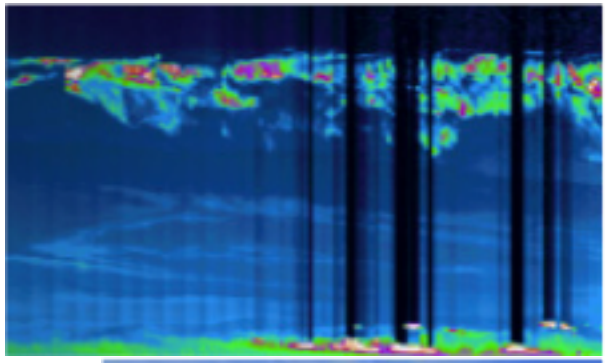
[a] Model = MERRA-2 time-step of 30 minutes with spatial resolution of 0.5° latitude × 0.625° longitude.
[b] latitude × longitude
[c] Resolution is for source map (Ginoux et al., 2001); wind-driven emissions at model time-step and grid.



Evaluation & Inter-Comparisons

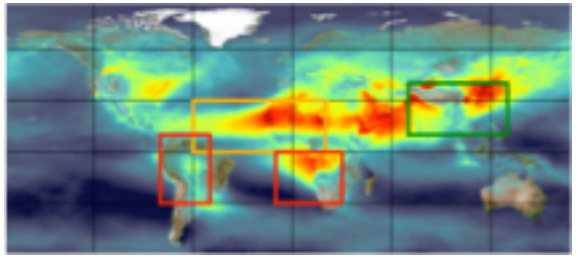
MERRA-2 Aerosol Evaluation Highlights

Using Independent Observations

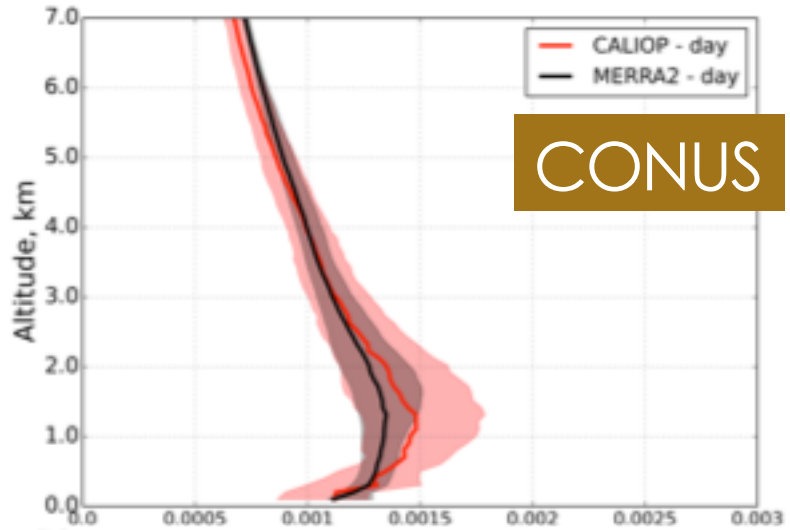


Vertical Structure

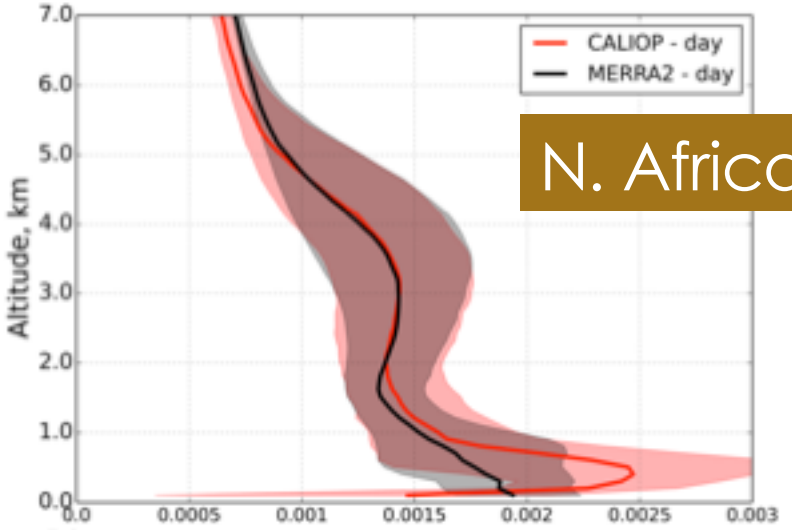
Comparison to CALIOP



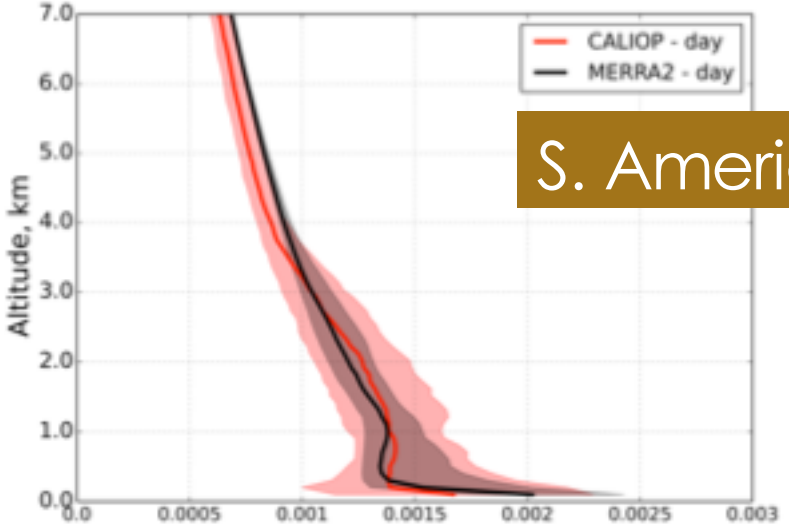
Attenuated Backscatter km^{-1} sr^{-1}



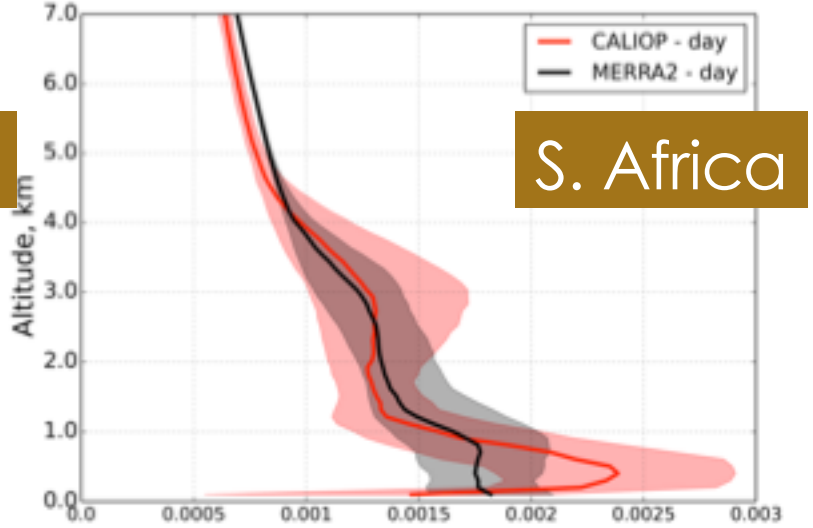
CONUS



N. Africa



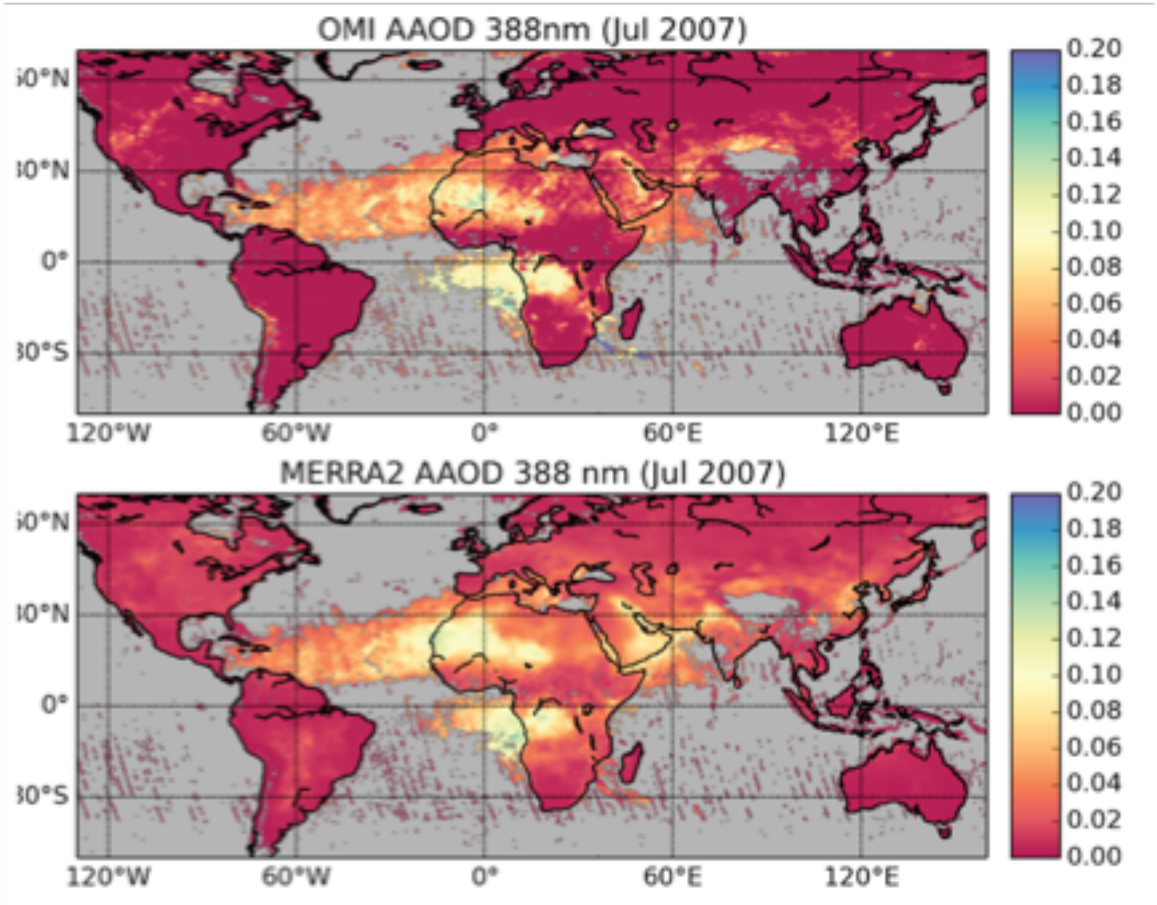
S. America



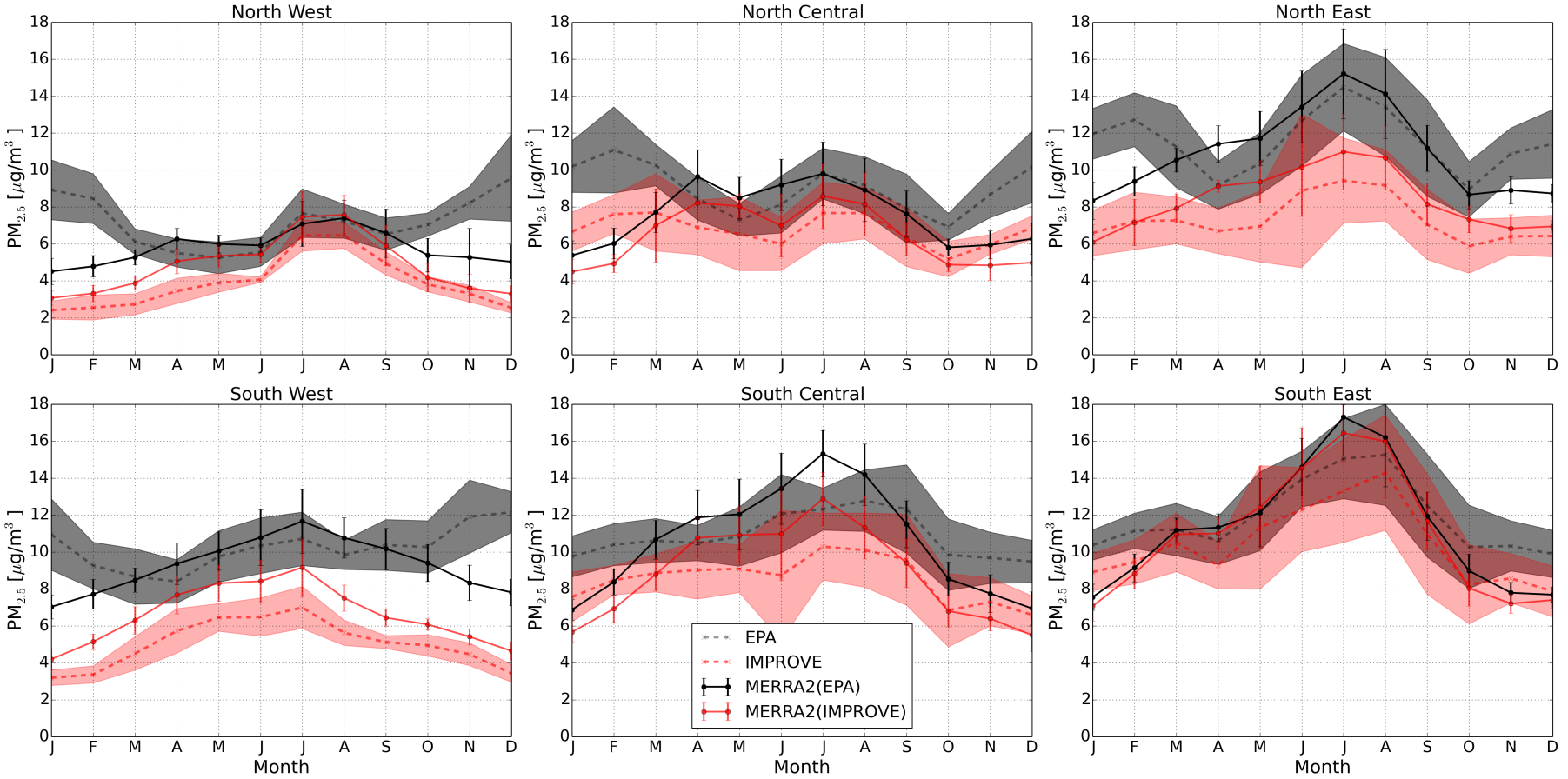
S. Africa

Aerosol Absorption

- Comparison of MERRA-2 Absorption Optical Depth (AAOD) with OMI retrievals
- Good agreement for African dust and smoke
- North American biomass burning underestimated according to OMI



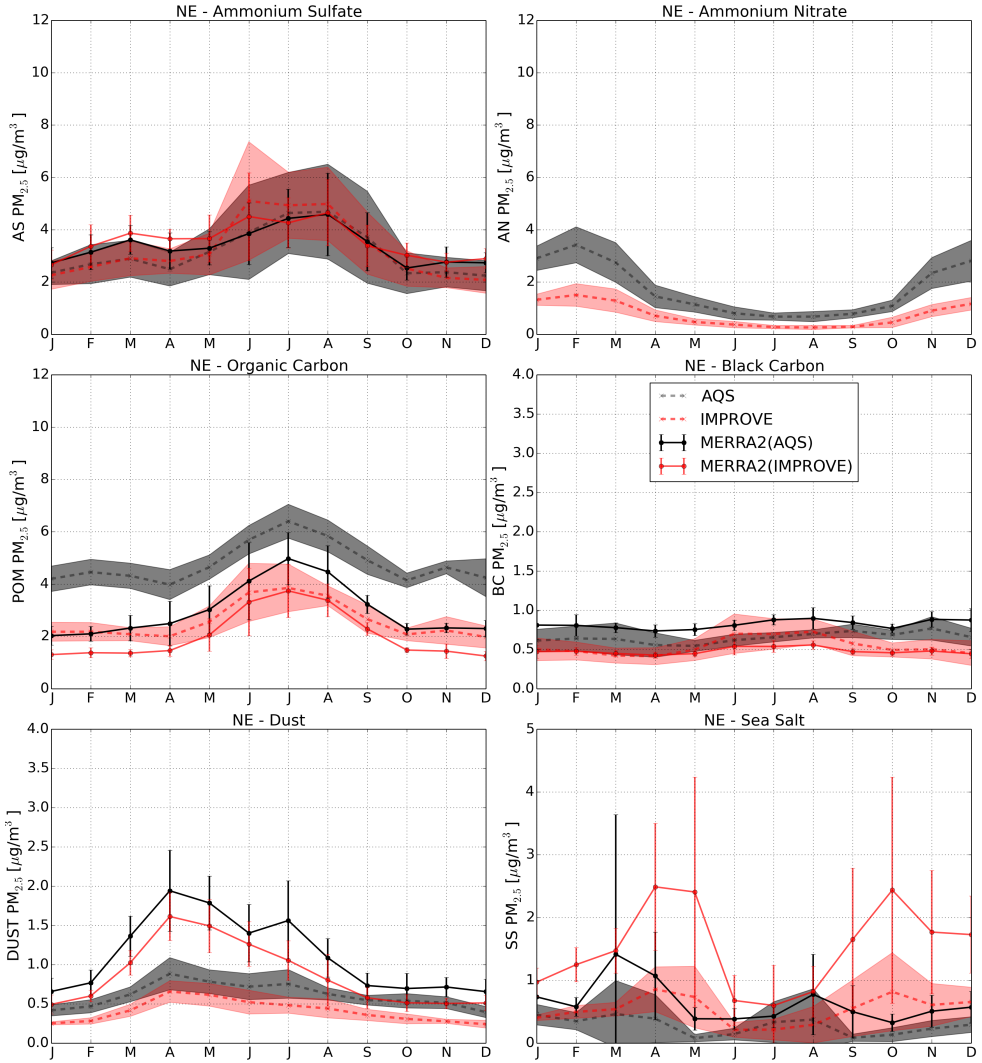
$PM_{2.5}$ (Total) Regional Climatology



Comparison with in-situ measurements

$PM_{2.5}$ by Species in the Northeast

- Relatively good agreement for **sulfates**
- MERRA-2 lacks **nitrates** altogether
- Underestimation of **carbonaceous** near-urban areas
- Too much **dust**
- Too much **sea salt** at coastal stations



MERRA-2 Status

- MERRA-2 has officially been released. Data access through the GES DISC:
  - http://disc.sci.gsfc.nasa.gov/daac-bin/FTPSubset2.pl
  - https://disc.gsfc.nasa.gov/datasets?keywords=merra-2&page=1
- The MERRA-2 file specification document is available at:
  - http://gmao.gsfc.nasa.gov/pubs/ under the tab *Office Notes (GMAO Office Note No. 9)*
- NASA tech memos documenting the MERRA-2 meteorological and aerosol validation are available at:
  - https://gmao.gsfc.nasa.gov/reanalysis/MERRA-2/docs/
- MERRA-2 Aerosol publications:
  - Randles et al., Journal of Climate, 2017, DOI: 10.1175/JCLI-D-16-0609.1
  - Buchard et al., Journal of Climate, 2017, DOI: 10.1175/JCLI-D-16-0613.1

Exercise: Create a visualization of MERRA-2 output using Giovanni

- Select your event from the list below
  - Fires in Canada and Smoke Transport Over the U.S., June 09, 2015
    http://earthobservatory.nasa.gov/IOTD/view.php?id=86011&eocn=image&eoci=related_image
  - Buffalo Fires, Wyoming, August 13, 2016
    http://go.nasa.gov/2cWvi9z
  - Saharan Dust Crosses the Atlantic, June 1, 2010
    http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=44169
  - Fires in Indonesia, September 24, 2015:
    http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=86681
  - Fires in Australia, February 10, 2014:
    http://earthobservatory.nasa.gov/IOTD/view.php?id=83117
  - Haze Over Eastern Asia, February 25, 2014:
    http://earthobservatory.nasa.gov/IOTD/view.php?id=83213

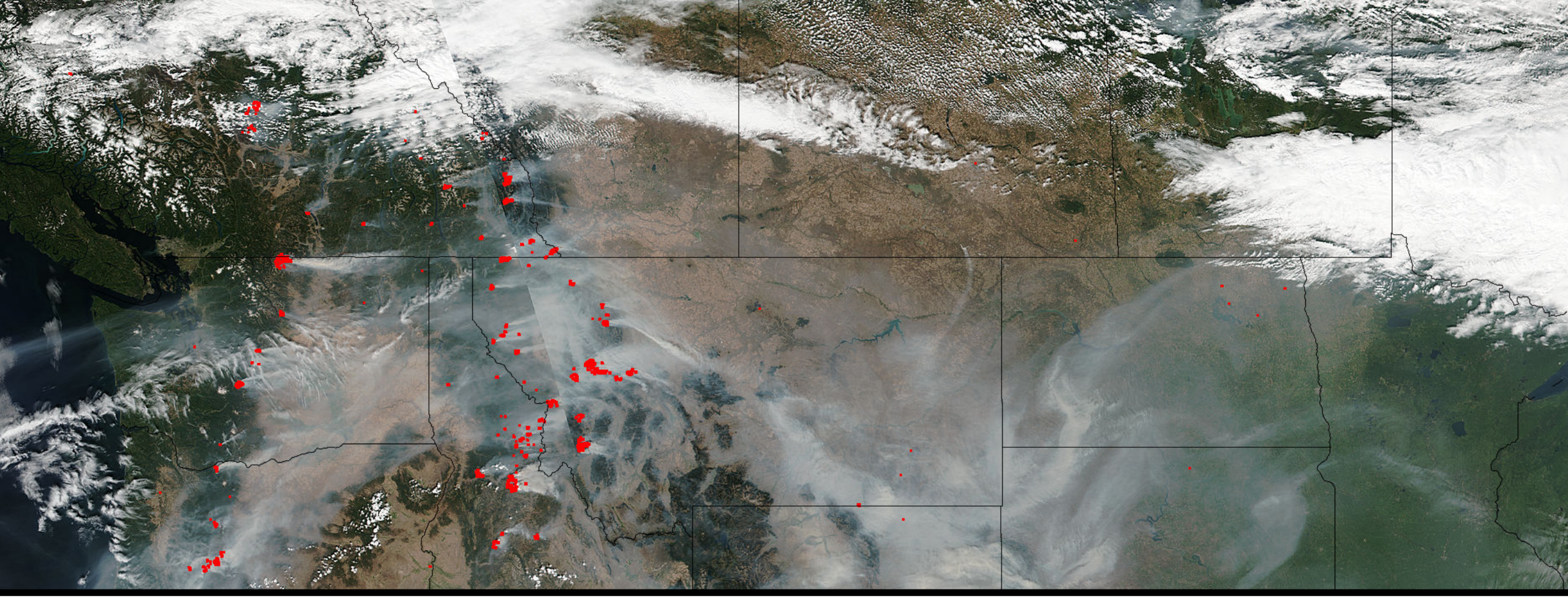
Exercise: Create a visualization of MERRA-2 output using Giovanni

https://giovanni.gsfc.nasa.gov/giovanni/

- On the left side, under Platform/Instrument, select MERRA-2 model

Exercise: Create a visualization of MERRA-2 output using Giovanni

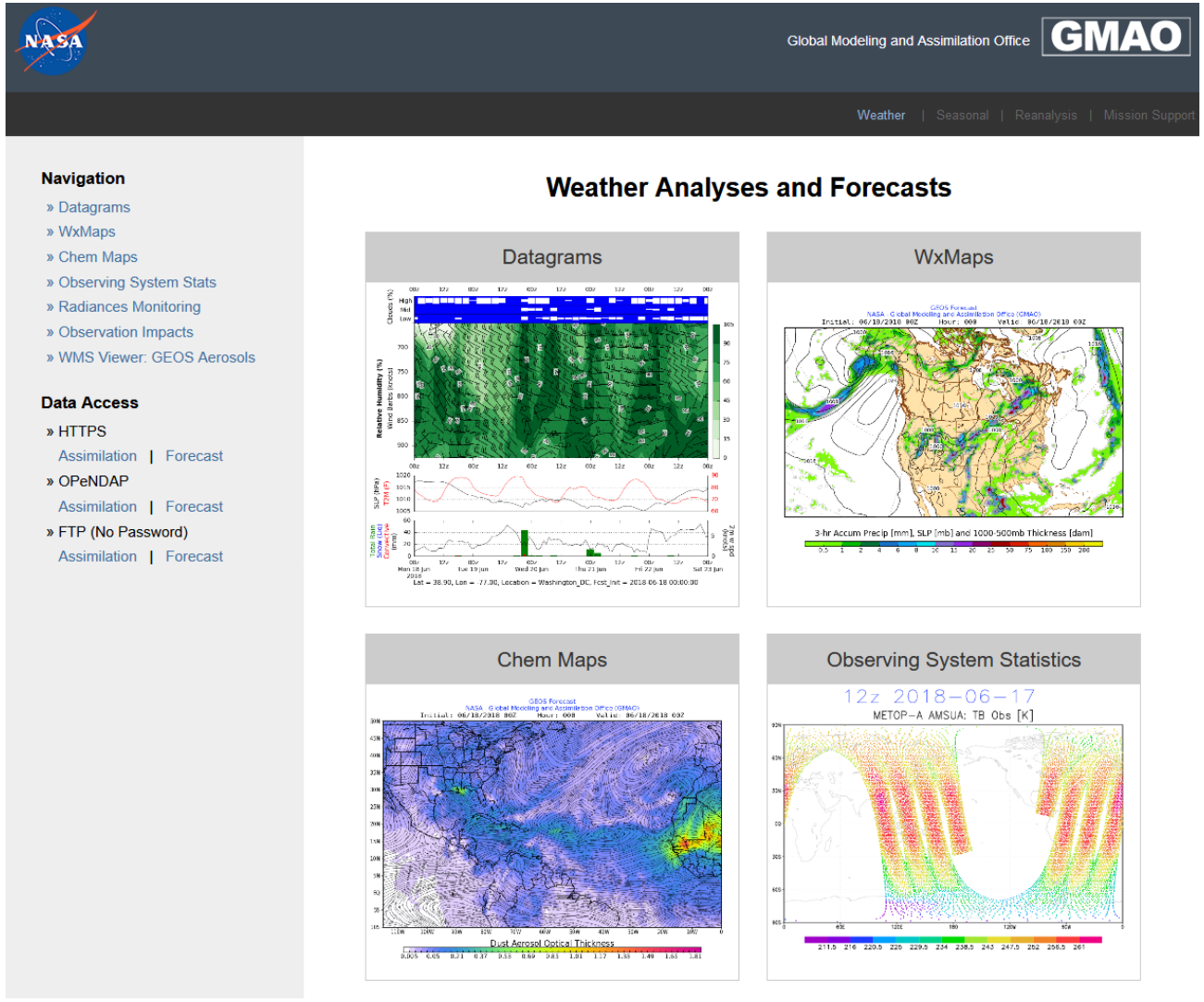
- Select the appropriate geophysical parameter relevant to the air quality event (i.e. dust AOD for dust transport, BC for fires, etc.)
- Create any one of the following visualizations
  - Multi day animation map showing the event
  - Time series over a certain region showing the impact of event
  - Time averaged maps



NASA GEOS Forecasts

NASA Forecasts: https://fluid.nccs.nasa.gov/weather/

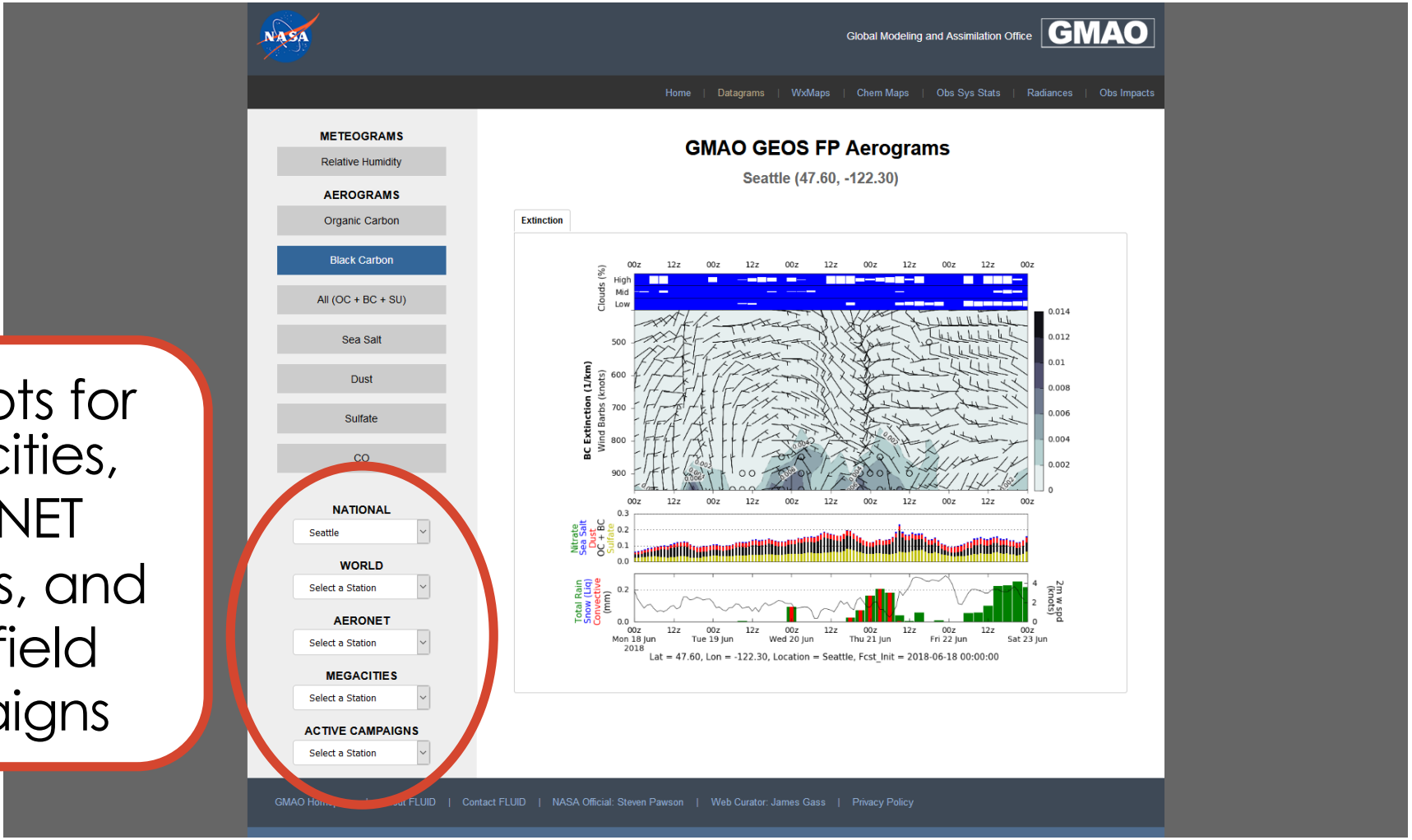
- NASA's global weather and atmospheric composition forecasts
  - Currently, the forecast system does include aerosols and CO, but not other trace gases like ozone and NO_2



NASA GMAO

NASA Atmospheric Composition Forecasts: Datagrams

View plots for select cities, AERONET locations, and NASA field campaigns



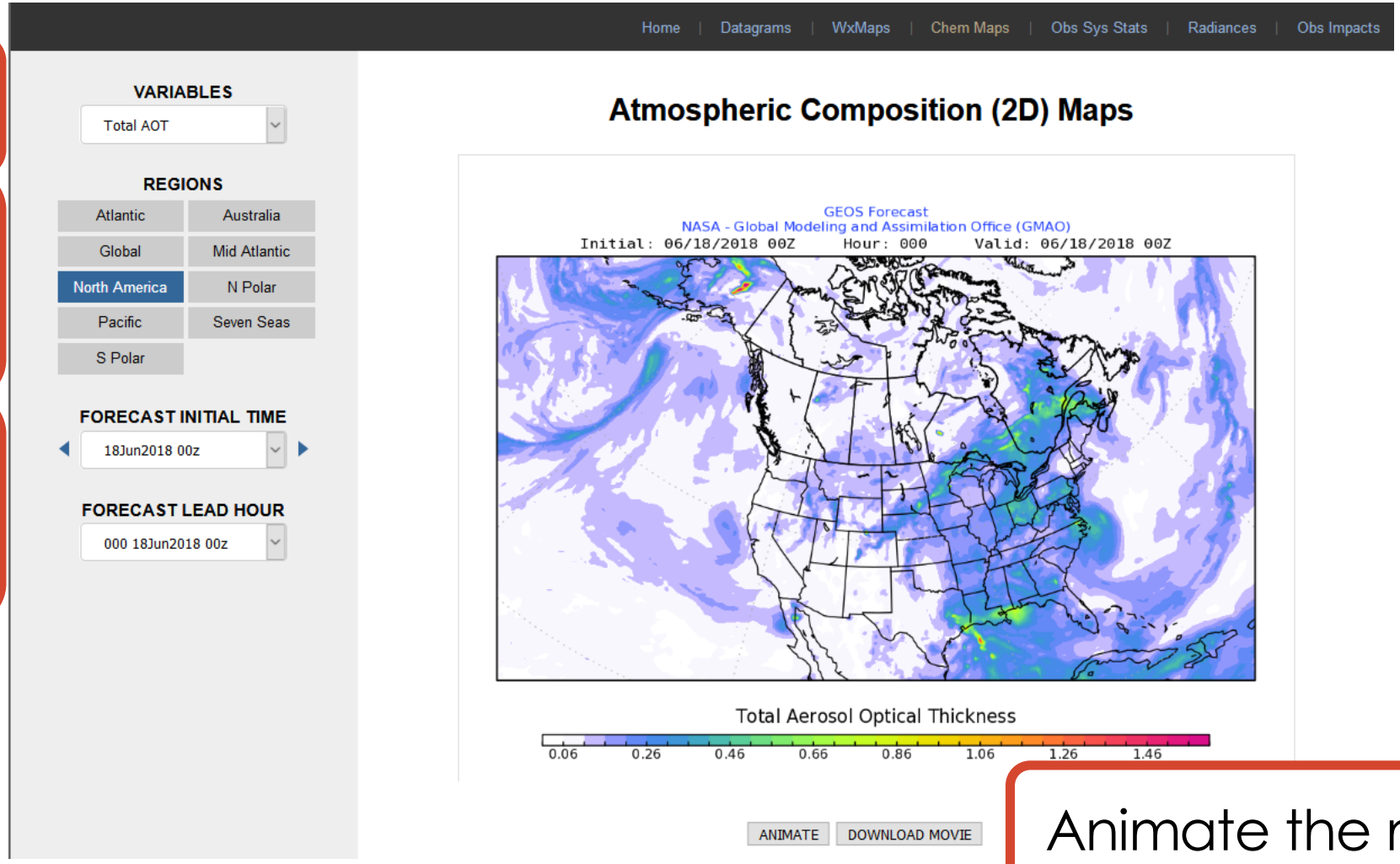
NASA GMAO

NASA Atmospheric Composition Forecasts: Chem Maps

Select a variable

Select a map region

Select a forecast



Animate the map

NASA GMAO

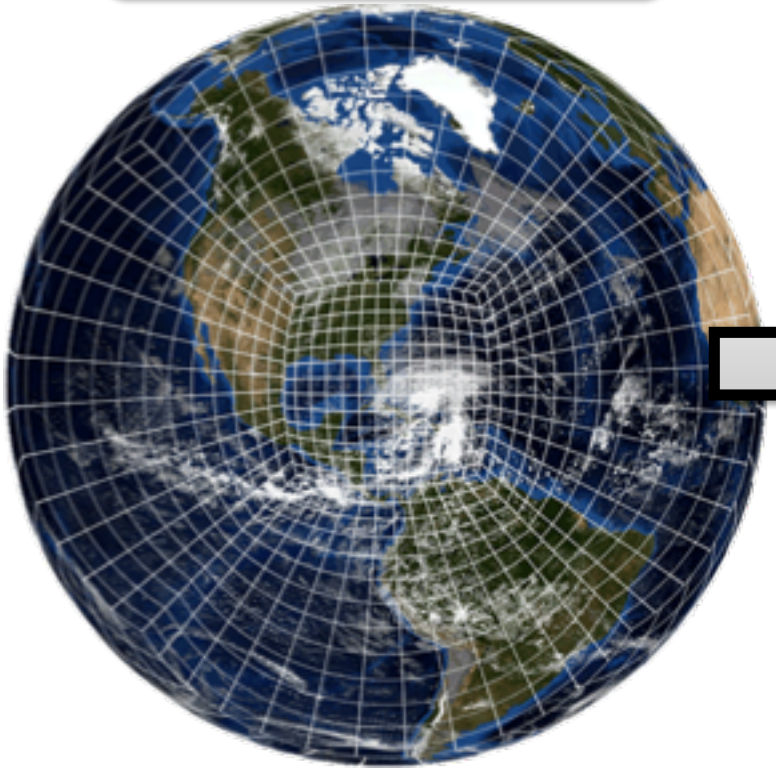
NASA Atmospheric Composition Forecasts: Exercise

- Compare the forecast for the chemical composition of aerosols in Spokane to that in Washington, DC

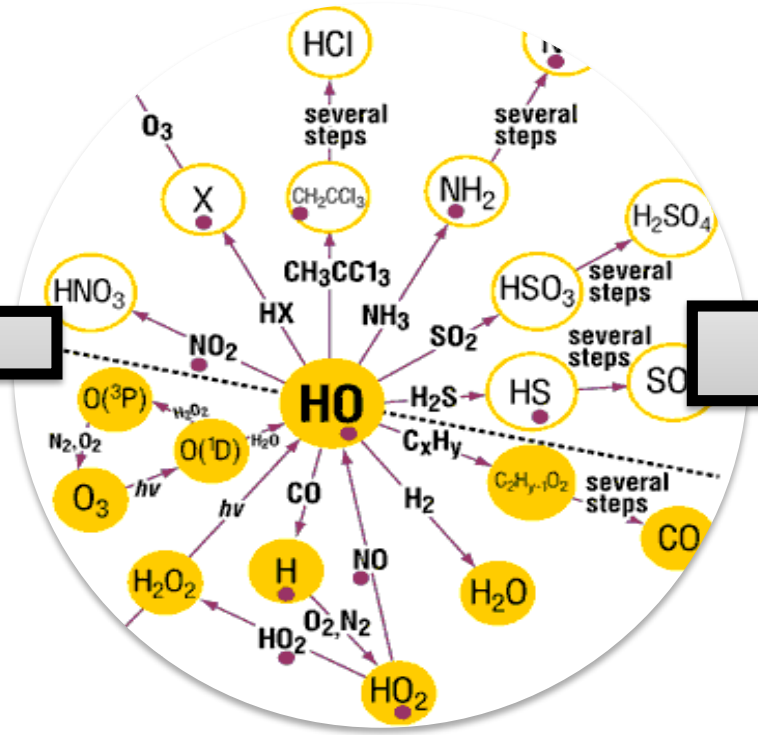
NASA GMAO

NASA's Upcoming Composition Forecasts (GEOS-CF)

GEOS-FP



GEOS-Chem

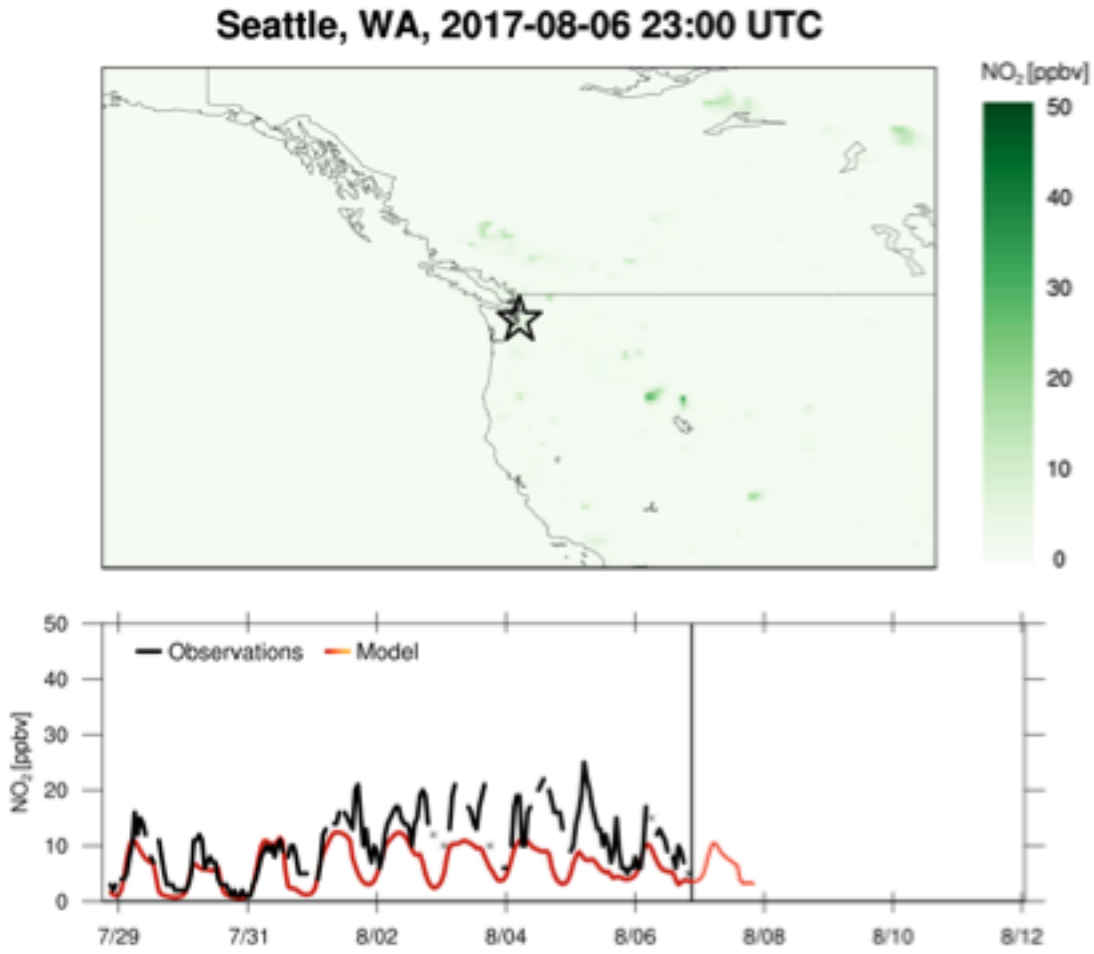


GEOS-CF

- 1-day analysis
- 5-day forecast
- O_3, NO_x, VOCs, PM …
- 0.25° resolution

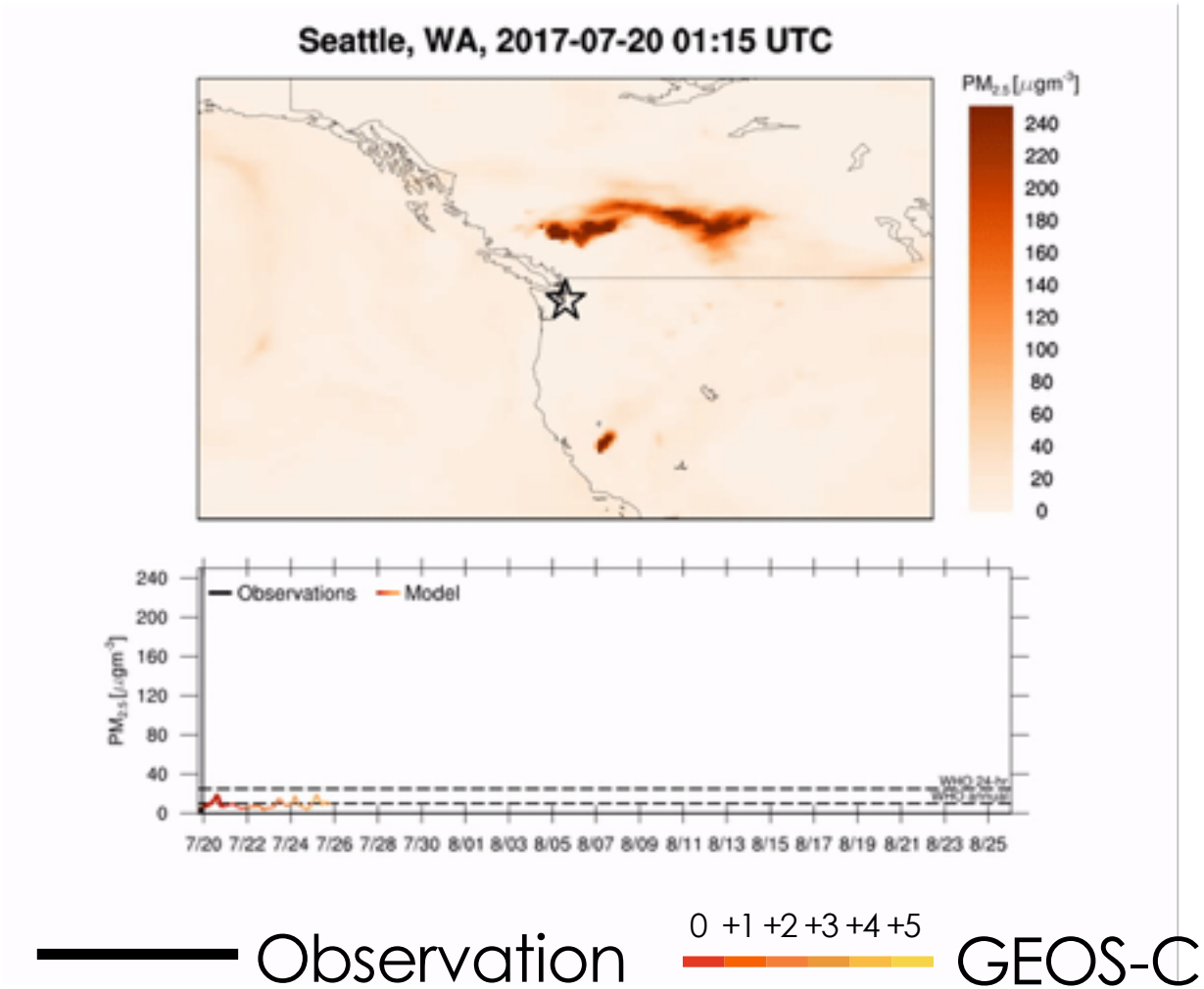
NASA's Upcoming Composition Forecasts

- NASA's global weather and atmospheric composition forecasts
  - Currently, the forecast system does include aerosols and CO, but not other trace gases like ozone and NO_2
  - At some point in 2018, surface particulate matter, ozone, NO_2, and other trace gases will be added to the system



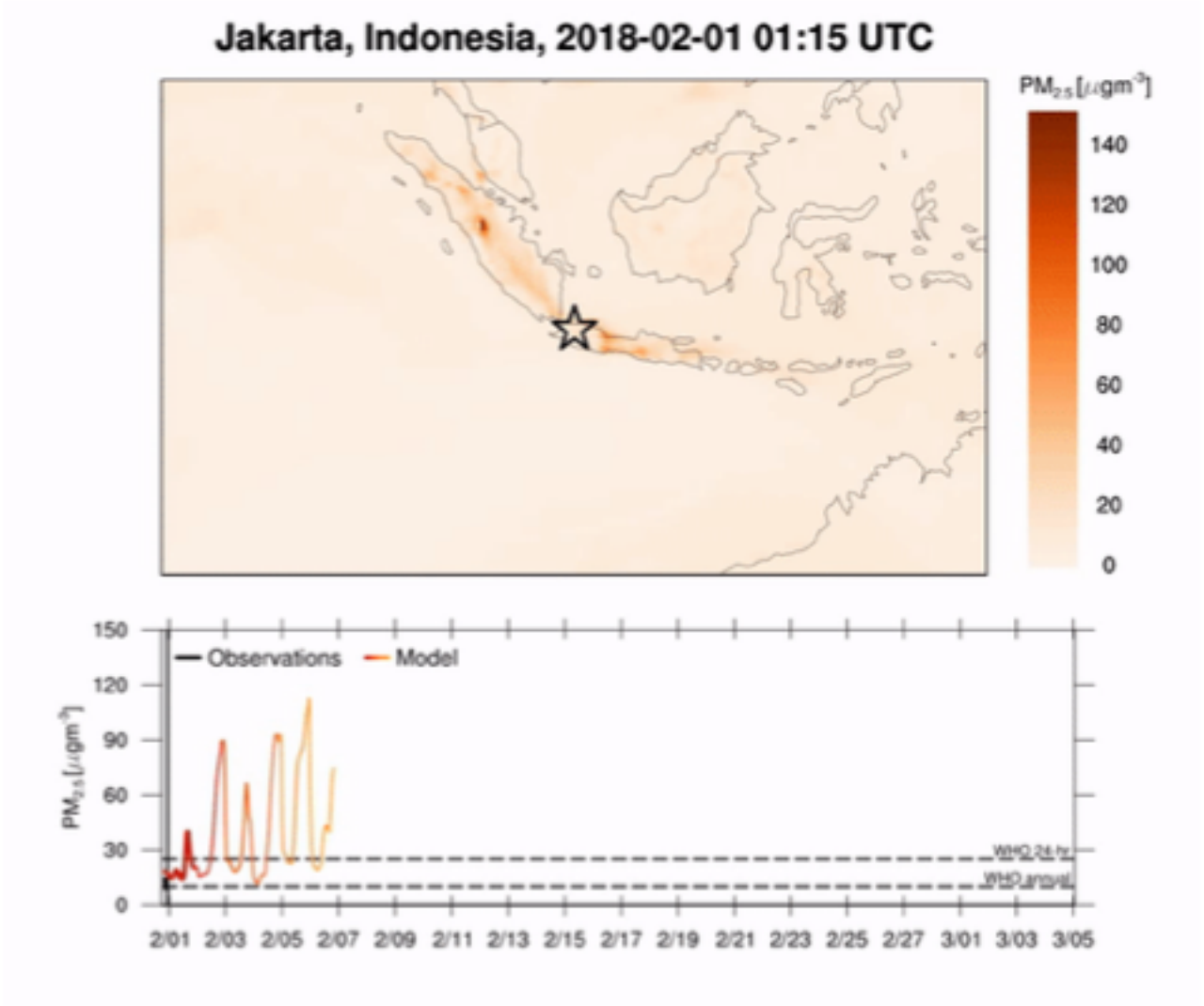
Christoph Keller, NASA GMAO

NASA's Upcoming Air Quality Forecasts



Christoph Keller, NASA GMAO

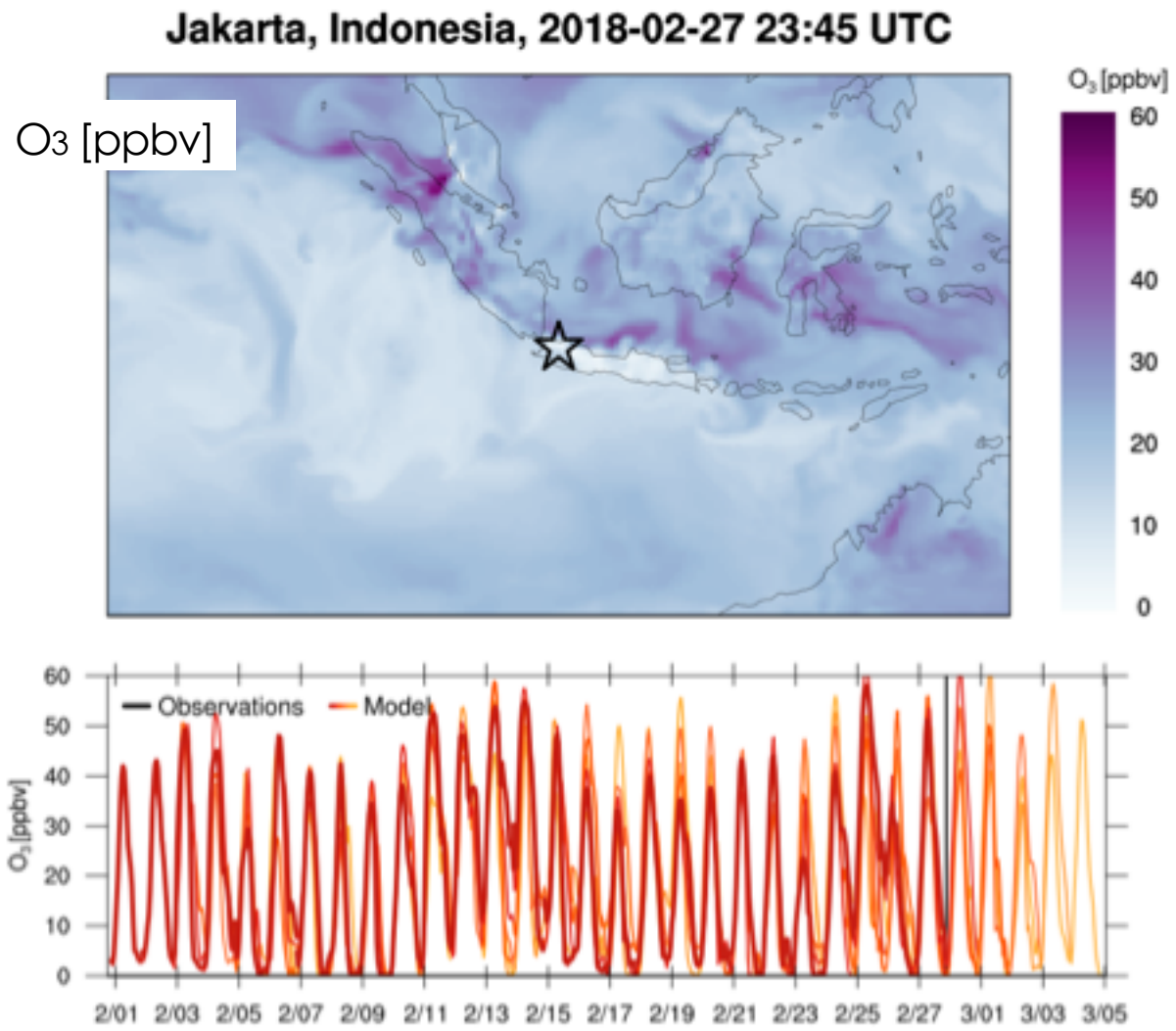
NASA's Upcoming Air Quality Forecasts



Christoph Keller, NASA GMAO

NASA's Upcoming Air Quality Forecasts

O3 [ppbv]



NO2 [ppbv]